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INSPECTION OF VEGETATION FOR SULFUR DIOXIDE EFFECTS

CUMBERLAND HEIGHTS, TENNESSEE - SEPTEMBER 16-30, 1981

AIR RESOURCES PROGRAM

TVA/ONR/ARP-82/7

TENNESSEE VALLEY AUTHORITY

Office of Natural Resources

Air Resources Program

INSPECTION OF VEGETATION FOR SULFUR DIOXIDE EFFECTS

CUMBERLAND HEIGHTS, TENNESSEE - SEPTEMBER 16-30, 1981

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December 1981

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Summary

The Jersey Miniere Zinc Company (JMZ) had an excessive release of sulfur dioxide (SO_2) during startup of their sulfuric acid plant on September 9, 1981. TVA biologists assisted the Tennessee Division of Air Pollution Control (TDAPC), at their request, in determining the impact of the JMZ exposure on vegetation.

Light to severe foliar effects attributable to SO_2 emissions from JMZ were observed on 108 species of vegetation in one area, about 1000 acres, located 0.3 to 3.2 miles southeast of the emission source. About three quarters of the affected species, 79 of 108, were economically important. Twenty-four complaints were investigated and SO_2 effects were observed on ornamentals, garden crops, and fruit crops belonging to 20 growers.

There were no SO_2 monitors located in the affected area. Consequently, the SO_2 concentrations associated with foliar injury could not be determined.

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INSPECTION OF VEGETATION FOR SULFUR DIOXIDE EFFECTS

CUMBERLAND HEIGHTS, TENNESSEE - SEPTEMBER 16-30, 1981

Introduction

On September 9, 1981, officials of Jersey Miniere Zinc Company (JMZ) reported to the Tennessee Division of Air Pollution Control (TDAPC) that startup of their sulfuric acid plant earlier in the day had resulted in a release of excessive sulfur dioxide (SO_2) to the atmosphere. John Russell, Director of Civil Defense, Clarksville, Tennessee, reported to TDAPC on September 10 that several residents near JMZ, particularly those in the immediate vicinity of Cumberland Heights Elementary School, about one mile southeast of the emission source, had complained that the air pollutants emitted from JMZ had affected their garden crops and ornamentals. On September 14, Mr. Harold E. Hodges, Director of TDAPC, requested that TVA assist his staff in determining the impact of the September 9, SO_2 release on vegetation in the vicinity of Cumberland Heights.

Methods

On September 16-18, a detailed systematic botanical survey for SO_2 effects was conducted in an area ranging from 3 to 6 miles from the JMZ SO_2 emission source. Methods used in conducting the survey are described in appendix A. During the survey, and again on September 22-24 and 30, complaints of air pollution effects to vegetation were investigated.

These investigations included documentation of affected species belonging to each grower and systematic estimates of injury observed on these species. The observations were used to supplement botanical survey results.

Results

Extent and Degree of Effects

Light to severe foliar effects[1] attributable to SO_2 exposure were observed on 108 species of vegetation (table 1), in one area located 0.3 to 3.2 miles southeast of the emission source (figure 1). The affected area, which was about one-half mile wide and almost three miles long, contained about 1,000 acres. The most extensive effects were observed on giant ragweed, which was the principal species used to delineate the affected area.

The most severe effects and the largest number of affected species (102) were observed 0.4 to 1.4 miles from the emission source in a 200-acre portion (area A, figure 1) of the affected area. In area A, effects were observed on several species that are relatively resistant to SO_2 (Appendix B) and on large trees which are generally much more resistant to SO_2 than small trees of the same species. Light to severe effects were observed on 42 species, including moderately sensitive species and small trees, 0.3 to 2.1 miles from the emission

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1. Percentage of total leaf area affected on an average affected plant: 0-10 = light, >10-25 = moderate and >25 = severe.

Table 1

DEGREE OF SULFUR DIOXIDE EFFECTS OBSERVED ON VEGETATION
CUMBERLAND HEIGHTS, TENNESSEE - SEPTEMBER 16-30, 1981

Species	Economic Importance[b]	Percentage Necrosis (N) Observed on an Average Affected Plant and Percentage of Plants (P) Affected[a]					
		Area A		Area B		Area C	
		N	P[c]	N	P	N	P
African violet (Gesneriad sp.)	3	18	100				
Annual lespedeza (Lespedeza sp.)	1	4-9	50-80	4-6	10-90		
Apple (Pyrus malus)	2	1-27	100	1	50		
August lilly (Lilium sp.)	3	20	100				
Beefsteak plant (Perilla frutescens)	0	36	90	18	50		
Beggar lice (Desmodium sp.)	0	2-9	50-100	6	30		
Begonia (Begonia sp.)	3	25-90	100				
Black cherry (Prunus serotina)[d]	2	15	100				
Black locust (Robinia pseudoacacia)[d]	2	9	30				
Black oak (Quercus velutina)	2	10-25	100				
Black walnut (Juglans nigra)[d]	2	21-60	100	18	100		
Blackberry (Rubus sp.)	0	4-36	90-100	1-15	10-30		
Box elder (Acer negundo)	2	2-24	60-100				
Caladium (Caladium sp.)	3	25	100				
Canna (Canna sp.)	3	1	70				
Catalpa (Catalpa sp.)[d]	2			12	100		
Chrysanthemum (Chrysanthemum sp.)	3	1-56	10-100				
Cocklebur (Xanthium sp.)	0	9-36	80				
Cockscomb (Celosia sp.)	3	12	20				
Coleus (Coleus sp.)	3	24	100				
Crownbeard (Verbesina occidentalis)	0	9	40	3-18	10		
Cucumber (Cucumis sativus)	1	6	90	3	80		
Devils-walking-stick (Aralia spinosa)	0	12	100				
Dish rag gourd (Lagenaria sp.)	3	56	100	4-40	70-100		
Dogwood (Cornus florida)	2	2-12	50-100	12	100		
Domestic grape (Vitis sp.)	1	4-28	30-100				
Domestic sunflower (Helianthus sp.)	3	56	100				
English dogwood (Cornus alternifolia)	3	35	80	4	50		
Fern (Nephrolepis exalata)	3	6-22	100				
Field pea (Vigna sinensis)	1	2	10				

Table 1

(Continued)

Species	Economic Importance[b]	Percentage Necrosis (N) Observed on an Average Affected Plant and Percentage of Plants (P) Affected[a]					
		Area A		Area B		Area C	
		N	P	N	P	N	P
Florida beggarweed (Desmodium tortuosum)	0	16	100				
Flowering crabapple (Pyrus sp.)	2	14-95	100				
Four-o'clock (Mirabilis jalapa)	3	4	100	2	20		
Forsynthia (Forsynthia sp.)	3	10-18	100	1	10		
Fuchsia (Fuchsia sp.)	3	50	100				
Geranium (Germanium sp.)	3	90	100				
Giant ragweed (Ambrosia trifida)	0	30-81	70-100	24-63	90-100	12-56	70-100
Goldenrod (Solidago sp.)	0	28	80			30	80
Gourd (Lagenaria sp.)	3			8	100		
Ground cherry (Physalis alkekengi)	0			4	100		
Hackberry (Celtis sp.)[d]	2	12	100	8-21	100		
Hibiscus (Hibiscus sp.)	3	3-30	30-100			24	100
Hickory (Carya sp.)	2	2-3	10-100	25	80		
Honey locust (Gleditsia triacanthos)[d]	2	2	100				
Honeysuckle (Lonicera japonica)	0	1	10				
Horsenettle (Solanum carolinense)	0	6	100				
Hydrangea (Hydrangea sp.)	3	9-30	60-100				
Impatiens (Impatiens sp.)	3	70	100				
Ladys-thumb (Polygonum persicaria)	0	28	100				
Lawn grass (several species)	3			2	10		
Lesser ragweed (Ambrosia artemisiifolia)	0	1-35	90-100	6-35	10-100	6	50
Loblolly pine (Pinus taeda)	2	49	30				
Lombardy poplar (Populus nigra)	2	25	100				
Maple (Acer sp.)	2	5-18	60-100	5-9	30-100		
Marigold (Tagetes patuda)	3	15-20	100	4-15	100		
Mimosa (Mimosa sp.)	2	1-10	30-100				
Morning glory (Ipomoea sp.)	0-3[e]	1-35	20-100	6-21	60-100		
Okra (Hibiscus esculentus)	1	1-35	80-100				
Peach (Prunus persica)	2	1	50				
Pear (Pyrus communis)	2	18	100				
Pecan (Carya illinoensis)	2	20	100				
Peony (Paeonia albiflora)	3			18	100		

Table 1

(Continued)

Species	Economic Importance[b]	Percentage Necrosis (N) Observed on an Average Affected Plant and Percentage of Plants (P) Affected[a]					
		Area A		Area B		Area C	
		N	P	N	P	N	P
Pepper (Capsicum sp.)	1	1-24	100	1	30		
Persimmon (Diospyros virginiana)[d]	2	12	10	6	100		
Pigweed (Amaranthus sp.)	0	2	20				
Pokeweed (Phytolacca americana)	0	8-36	20-100	6	100		
Portulaca (Portulaca sp.)	3	42	100				
Privet (Ligustrum vulgare)	3	32-36	70-100	1	100		
Pumpkin (Cucurbita pepo)	1	2	100				
Pyracantha (Pyracantha sp.)	3	2-15	100				
Raspberry (Rubus idaeus)	1	6	100				
Red clover (Trifolium pratense)	1	1-6	10-100	4	40		
Red elm (Ulmus rubra)	2	2-48	100				
Redbud (Cercis canadensis)	2	6	100	2-9	60-100		
Rose (Rosa sp.)	3	3-48	100	9	50		
Rose of Sharon (Hibiscus syriacus)	3	6-30	50-100				
Sassafras (Sassafras albidum)	0[f]	9-16	50-100	15-24	30-50		
Serecia (Lespedeza cuneata)	1	2	10				
Smartweed (Polygonum sp.)	0	15-54	50-90				
Smooth sumac (Rhus glabra)	0	20-36	100				
Snap bean (Phaseolus vulgaris)	1	12-18	70-80				
Southern red oak (Quercus falcata)	2	27	100				
Spider-flower (Cleome sp.)	3	15-35	80-100				
Spiny amaranth (Amaranthus spinosus)	0	18	100				
Spirea (Spiraca sp.)	3	30	100				
Spurge (Euphorbia sp.)	0	12	50				
Squash (Cucurbita sp.)	1	24	100				
Strawberry (Fragaria sp.)	1	12	100				
Sumpweed (Iva annua)	0					12	10
Sweet clover (Melilotus sp.)	0	12	90				
Sweet potato (Ipomoea batatas)	1	2	100				
Sweetgum (Liquidambar styraciflua)	2	9-20	100	12	50		

Table 1

(Continued)

Species	Economic Importance[b]	Percentage Necrosis (N) Observed on an Average Affected Plant and Percentage of Plants (P) Affected[a]					
		Area A		Area B		Area C	
		N	P	N	P	N	P
Sycamore (Platanus occidentalis)[d]	2	18	100	12	100		
Tickseed sunflower (Bidens aristosa)	0	24	90				
Tomato (Lycopersicon esculentum)	1	1-28	10-100	1-6	50-100		
Tuliptree (Liriodendron tulipifera)	2	9-56	20-100	32	10		
Turnip (Brassica rapa)	1	20-36	90-100	15	90		
White ash (Fraxinus americana)	2	12-25	100	12-21	80-100	24	50
White pine (Pinus strobus)	2	28-48	100				
Wild carrot (Daucus carrota)	0	4	50				
Wild grape (Vitis sp.)	0	4-21	100	1-6	100		
Wild sunflower (Helianthus sp.)	0	12	80	28	100		
Winged sumac (Rhus copallina)	0	90	100	18	60		
Woodnettle (Urtica sp.)	0	6	100				
Woody legume (unidentified)[g]	3	16	100				
Yellow Rose of Texas (Rosa sp.)	3	1-2	10-100				
Yellow flowering annual (unidentified)[g]	3	2	100				
Zinnia (Zinnia sp.)	3	30	100	12	100		
Total affected species per area		102		43		6	
Total affected species		108					

a. Range for all observations at data points where species was affected. Note: Some species were not affected at all data points. No-effects observations are not included.
b. 0 - none; 1 - field or garden crop; 2 - commercial or ornamental tree; 3 - other ornamental
c. In some cases only one plant of a species was observed per data point.
d. Affected trees <15 ft. tall.
e. Species growing as an ornamental at one site in area A.
f. Growing as a weed tree.
g. Flowers and/or fruit necessary for identification not present.

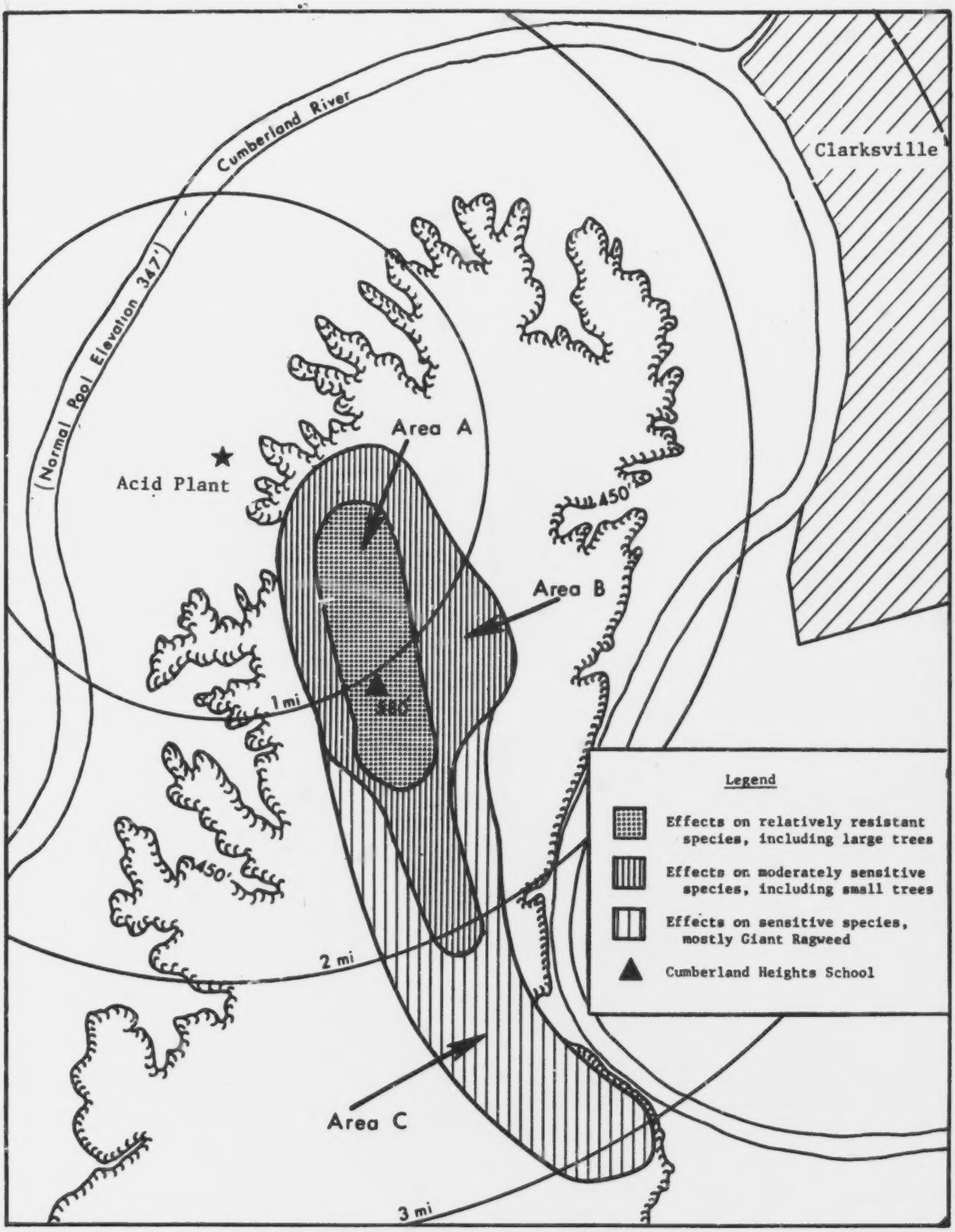

Figure 1. AREA WHERE SULFUR DIOXIDE EFFECTS WERE OBSERVED ON VEGETATION CUMBERLAND HEIGHTS, TENNESSEE - SEPTEMBER 16-30, 1981

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source in a 400-acre portion (area B) of the affected area. In area C, a 400-acre portion of the affected area farthest from the emission source, light to severe effects were observed on only six species. Most of the effects observed in area C were on weed species, primarily giant ragweed.

Effects to Economically Important Species

Almost three quarters of the affected species (79 of 108) are economically important (table 2). This includes 16 field and garden crop species, 28 commercial or ornamental tree species, and 35 other ornamental species. However, effects observed on some species were not economically significant. For example, effects were observed on three field crop species (annual lespedeza, red clover, and serecia) but none were observed in commercial plantings of these crops. The affected crop species were growing along roadways, edges of yards, and in abandoned fields. Similarly some of the affected commercial or ornamental tree species were observed only along highway right-of-ways.

The largest number of economically important species--75--were observed in area A, compared with 30 in area B and only 2 in area C. Not all individual plants of affected species in areas A and B were injured. However, individuals of any species affected in each of these areas (table 1) could have been injured anywhere within that area depending on localized SO_2 concentration, genetic sensitivity of individual plants, and other factors that affect the sensitivity of vegetation to SO_2.

Table 2

ECONOMIC IMPORTANCE OF VEGETATION EXHIBITING SULFUR DIOXIDE EFFECTS
CUMBERLAND HEIGHTS, TENNESSEE - SEPTEMBER 16-30, 1981

	Number of Affected Species					
	Economically Important					
Area	Field or Garden Crop	Commercial or Ornamental Tree	Other Ornamental	Total	No Economic Importance	Total
A	16	27	32	75	27	102
B	6	13	11	30	13	43
C	0	1	1	2	4	6
All Areas	16[a]	28[a]	35[a]	79[a]	29[a]	108[a]

a. Less than the sum of above because the same species were affected in more than one area.

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Effects were observed on economically important species only at two locations in area C. These effects consisted of moderate injury to ornamental hibiscus at one residence and small white ash trees (<6' tall) growing under the canopy of a deciduous forest about three miles from the emission source.

TDAPC received complaints of SO_2 injury to vegetation from 27 residents in the Cumberland Heights area. Almost all of these complaints were referred to TDAPC by Mr. John Russell or by another complainant. Twenty-four of the complaints were investigated. The other three complainants were not home when visited. Three of the 24 complainants contacted said they had not complained and did not have any air pollution injury on vegetation at their residences. Light to severe SO_2 injury was observed on ornamentals, garden crops, and fruit crops belonging to 20 growers (table 3). Of these growers, there were 12 in area A, 7 in area B, and only 1 in area C.

Correlation of Effects With Sulfur Dioxide Concentrations

There were no continuous SO_2 monitors located in the affected area. Consequently SO_2 concentrations associated with foliar injury could not be determined. However, foliar injury was observed on several species that are relatively resistant to SO_2 exposure (appendix B). Two of the resistant species affected, honeysuckle and strawberry, have been exposed in the Tennessee Valley to peak, 1-hour, and 3-hour SO_2 concentrations as high as 4.0, 1.3, and 0.7 parts per million respectively without exhibiting visible effects.

Table 3

SUMMARY OF COMPLAINT INVESTIGATIONS
CUMBERLAND HEIGHTS, TENNESSEE - SEPTEMBER 16-30, 1981

	Complaints							
	Area A		Area B		Area C		All Areas	
Vegetation Inspected	Total	With Effects	Total	With Effects	Total	With Effects	Total	With Effects
Ornamentals	12	12	8	7	1	1	21	20
Garden crops	10	9	5	4	0	0	15	13
Fruit crops[b]	10	10	4	1	1	0	15	11
Total	12[a]	12[a]	8[a]	7[a]	1[a]	1	21[a]	20[a]

a. Less than the sum of above because some growers had more than one type of vegetation.
b. Home orchards.

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Discussion

The alignment and location of the affected area in figure 1 (long axis radiating from the emission source), the distribution of effects (generally less severe with distance from the emission source), observations of ground-level wind direction and SO_2 odor by local residents, and the age of effects when first evaluated indicate that all SO_2 injury observed was caused by emissions from JMZ during the morning of September 9, 1981.

The economic impact of the JMZ SO_2 exposure was minimized because of the time of year (late fall) when the exposure occurred. Although effects were observed on 13 garden crop species, belonging to 13 growers, most gardens in the area had matured earlier and had been abandoned. Also, vegetation is more resistant to SO_2 exposure late in the growing season than during spring through mid-summer. During extensive field studies near SO_2 sources in the Tennessee Valley and other areas, mortality has not been associated with single acute SO_2 exposures. Although leaf tissue is killed and leaves may drop, affected plants generally put out new growth within one to two weeks after the exposure or during the next growing season, depending on the species and the time of the growing season when plants are injured. In the Cumberland Heights area, new growth was observed on several severely affected species, such as tomato, turnip and crabapple, before September 24.

Crop yield reduction associated with sulfur dioxide injury, (except for foliage crops such as turnip greens) is generally caused by

a reduction in leaf area which lowers the capacity for plants to produce seed or fruit. Foliar injury observed on some garden crop species in the Cumberland Heights area was sufficient to cause a reduction in yield.[2]

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2. Yield reductions are generally not detectable unless at least 5 percent of total leaf area is affected.

Conclusions

1. Light to severe foliar effects attributable to SO_2 emissions from JMZ were observed on 108 species of vegetation in one area which contained about 1,000 acres.
2. Almost three quarters of the affected species, 79 of 108, were economically important. However, effects observed on some of these species were not economically significant.
3. Sulfur dioxide effects were observed on ornamentals, garden crops, and orchard crops belonging to 20 growers that complained of air pollution effects.

Appendix A

Routine Botanical Surveillance Methods

The area where vegetation is inspected for sulfur dioxide (SO_2) effects is generally located within seven miles of the source. The limits are selected after considering such factors as stack height, total SO_2 emissions, topographic features, continuous SO_2 monitoring data, known occurrences of meteorological parameters that create poor dispersion conditions, and previous SO_2 exposures that affected vegetation in the vicinity of the source. (When affected vegetation is observed to the limits of a routinely surveyed area, that area is surveyed as far from the source as effects can be detected.) The surveys are begun near the source because vegetation is generally affected more severely in the portion of an affected area nearest the emission source. Therefore, in this area it is easier to locate SO_2 affected vegetation and establish the center line of the affected area so that light effects in more distant areas can be detected more readily. This minimizes the time necessary to conduct a survey and allows the survey to proceed in a systematic manner.

Vegetation is inspected along a network of roads around the source at about 1-mile intervals. In affected areas, surveillance is intensified and vegetation is inspected along most of the passable roads. The areas where vegetation is affected by SO_2 are delineated by using indicator species, such as giant ragweed, lesser ragweed, common evening primrose, and blackberry, which are known to be very susceptible to SO_2 exposure. As these areas are delineated, crops and ornamentals are inspected throughout the area and species exhibiting unusually severe effects attributable to SO_2 exposure or other agents are documented with 35-mm color slides. In some cases, typical specimens are collected for pathological examination.

After the affected areas are delineated, from 1 to 10 representative data points are selected in each area. This includes a data point at each continuous SO_2 monitor in the affected area and at other representative locations to show how the effects are distributed throughout the affected area. The number of data points selected in each affected area depends on (1) the size of the area, (2) the distribution of the affected species, (3) the variation in the degree of effects exhibited by each species, and (4) the number of SO_2 monitors within the area. At each of these points a list is made of affected and unaffected species (if practicable), and estimates are made of the degree of SO_2 injury exhibited by each affected species. The size of the data points generally range from linear roadway plots 50 yards to 2 miles long, depending on the diversity of species in the area, to circular plots that extend no further than 100 feet from continuous SO_2 monitors so that the degree of effects exhibited by each plant may be correlated with SO_2 exposure levels. Also, in some cases, a data point may consist of the area inspected (grower's property) during the investigation of a complaint.

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APPENDIX B

RELATIVE SENSITIVITY OF COMMON SPECIES TO SO_2 EXPOSURE[1]

SENSITIVE	MODERATELY SENSITIVE	RELATIVELY RESISTANT
* BLACK OAK	* ANNUAL LESPEDEZA	* APPLE
BLACKJACK OAK	* BLACK LOCUST	* BLACK CHERRY
* BLACKBERRY	BLACK WILLOW	* BLACK WALNUT
CAROLINA CRANESBILL	BLUEBERRY	BLACKGUM
COMMON CINQUEFOIL	CHESTNUT OAK	* BOXELDER
COMMON EVENING PRIMROSE	* COCKLEBUR	* CHRYSANTHEMUM
* CUCUMBER	COTTONWOOD	CORN
DAISY FLEABANE	* CULTIVATED ROSE	COTTON
FARKLEBERRY	* FIELD PEA	* DOGWOOD
* GIANT RAGWEED	* HICKORY	EASTERN REDCEDAR
* GOLDENROD	HOPHORNBEAM	* GRASS (MOST SPECIES)
* LESSER RAGWEED	LOBLOLLY PINE[3]	* HACKBERRY
* LOBLOLLY PINE[2]	* MORNINGGLORY	* HONEYLOCUST
SMALL'S RAGWORT	NORTHERN RED OAK	* HONEYSUCKLE
* SMOOTH SUMAC	* PENNSYLVANIA SMARTWEED	IRISH POTATO
ST. JOHNSWORT	* PERSIMMON	* MAPLE
SOYBEAN	POISON IVY	* OKRA
* SQUASH	* RED CLOVER	* PEACH
TULIPTREE (LATE MAY)	SHORTLEAF PINE	* PEAR
VENUS LOOKINGGLASS	* SOUTHERN RED OAK	POST OAK
VIRGINIA PINE[2]	* SWEET POTATO	* REDBUD
* WILD GRAPE	* SWEETGUM	* SASSAFRAS
* WILD SUNFLOWER	TALL COREOPSIS	* STRAWBERRY
* WINGED SUMAC	VIRGINIA PINE[3]	* SYCAMORE
* WHITE ASH	WHITE CLOVER	* TULIPTREE (SUMMER AND FALL)
* WHITE PINE	* WILD CARROT	WHITE OAK

1. BASED ON TVA OBSERVATIONS (1951-1981).
2. SEEDLINGS TO 6 FEET TALL.
3. >6 FEET TALL.

* EFFECTS OBSERVED ON THIS SPECIES IN THE VICINITY OF CUMBERLAND HEIGHTS, TENNESSEE, SEPTEMBER 16-30, 1981.